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A review on prospect of *Jatropha curcas* for biodiesel in Indonesia

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ABSTRACT

Energy is fundamental to the quality of life in the earth. Meeting the growing demand for energy sustainably is one of the major challenges of the 21st century. Indonesia is a developing country and the world's fourth most populous nation. Total annual energy consumption increased from 300,147 GWh in 1980, 625,500 GWh in 1990, 1,123,928 in 2000 and to 1,490,892 in 2009 at an average annual increase of 2.9%. Presently, fossil-fuel-based energies are the major sources of energy in Indonesia. During the last 12 years, Indonesia has recorded the most severe reduction in fossil fuel supplies in the entire Asia-Pacific region. This reduction has stimulated promoting the usage of renewable energy resources capable of simultaneously balancing economic and social development with environmental protection. Biodiesel is an alternative and environmentally friendly fuel that will participate in increasing renewable energy supply. *Jatropha curcas* is one of biodiesel resources that offer immediate and sustained greenhouse gas advantages over other biodiesel resources. Globally, *J. curcas* has created an interest for researchers because it is non-edible oil, does not create a food versus fuel conflict and can be used to produce biodiesel with same or better performance results when testing in diesel engines.

The present study is concerned with the prospect of biodiesel produced from *J. curcas* in Indonesia. The first part gives a summary and overview of energy resources and consumption in the country, second part discusses the potential of biodiesel as a powerful renewable energy resource and third part investigates the potential of *J. curcas* as a feedstock for biodiesel in Indonesia. The final part discusses the development of biodiesel market in Indonesia. The paper found out that the production of biodiesel from *J. curcas* offers many social, economical and environmental benefits for the country and can play a great role to solve the problem of energy crisis in Indonesia.

Contents

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1. Overview of energy resources and consumption in Indonesia

Energy is fundamental to the quality of life. It is a key input in all sectors of modern economics. Meeting the growing demand for energy sustainably is one of the major challenges of the 21st century. Indonesia is a developing country and the world's fourth most populous nation. Total population and energy needs are increasing day by day. It has been found that total population in Indonesia rose from 205,132,000 million in 2000 to 233,477,400 million in 2010 and projected to reach 273,219,200 million in 2025 as shown in Fig. 1. It is also expected that the total average increase in population growth between 2000 and 2025 is projected to be 33.2%. Thus, this issue must be addressed by the Indonesian government to overcome any shortage of energy resources in the future [1].

Total annual energy consumption increased from 300,147 GWh in 1980, 625,500 GWh in 1990, 1,123,928 in 2000 and to 1,490,892 in 2009 at an annual increase of 2.9% as can be seen in Fig. 2 [2].

In 2007, Indonesia ranks 15th among fossil-fuel CO_2 emitting nations. Emissions from the consumption of oil account for 40.9% of Indonesia's fossil-fuel CO_2 emissions. Emissions from natural gas consumption and coal usage, although quite variable, have risen steadily since the early 1970s and account for 15% and 38% of Indonesia's total emissions. With a population over 225 million people, Indonesia's per capita emission rate of 0.48 metric tons of carbon is well below the global average but has grown five-fold since the late 1960s [3].

Annual CO_2 emissions production has increased from 153.7 million tons in 1990 to 282.6 million tons in 2000 and reached 388.5 million tons in 2009 with an average annual increase of 8% as can be seen in Fig. 3 [2].

Presently, fossil-fuel-based energies such as oil, coal, and natural gas are the major sources of energy in Indonesia. In 2009, oil was the largest single source of energy (48%) followed by natural gas (26%), coal (24%) and renewables (2%) as shown in Fig. 4. It is expected that total fossil fuels consumption will increase by 52% by 2025 [2]. The largest consumer of fossils fuel is the industrial sector which reaches 48% from total national energy consumption in 2007 followed by the transportation sector (33%) as shown in Fig. 5.

Indonesia's oil production according to British petroleum [2] data decreased from 1,539,000 barrels per day in 1990 to 1,456,000 barrels per day in 2000 and 1021 million barrels per day in 2009. However, oil consumption increased from 685,000 barrels per day in 1990 to 1,122,000 barrels per day in 2000 and 1344 million barrels per day in 2009 as shown in Fig. 6.

Indonesia's natural gas production increased from 1,653,511,460 GJ in 1990 to 2,456,337,293 GJ in 2000 and 2,710,579,949 GJ in 2009. However, natural gas consumption increased from 637,537,257 GJ in 1990 to 1,120,672,409 GJ in 2000 and 1,380,782,966 GJ in 2009 as shown in Fig. 7.

Indonesia's coal production increased from 276,284,843 GJ in 1990 to 1,983,174,147 GJ in 2000 and 6,501,032,460 GJ in 2009. However, coal consumption increased from 165,546,072 GJ in 1990 to 574,261,488 GJ in 2000 and 1,275,997,399 GJ in 2009 as shown in Fig. 8.

Although the entire Asia-Pacific region has recorded some declines in oil supplies, Indonesia has reported more severe reduction in fossil fuels supplies during the last 12 years [5]. The current oil, natural gas and coal reserves in Indonesia are estimated to be 747 million cubic meters (4.7 billion barrels) of oil, 2557 million cubic meters (90,300 billion cubic feet) of natural gas and 4.968 billion ton of coal. For oil, this represents a 13% reduction in supplies and can be regarded as a significant decline because the current demand for oil has already exceeded the supply capacity of the oil industry (Fig. 6). Hence, there is an urgent need to overcome this crisis in Indonesia by trying to switch to sustainable energy resources. Unfortunately, the on-going development projects being implemented in this country are very dependent on the acquisition of these historical quantities of fossil fuels. Deficiencies in the energy supplies not only are relevant for the economic development at the country level but also have a significant impact for rural community dwellers and their livelihoods. Table 1 shows the reserve and life time of fossil fuels in Indonesia.

After a series of modest increases in fossil fuels prices since 2001 and the limited reserves of fossil fuels in Indonesia (Table 1) beside their growing emissions, the president of Indonesia, Yudhoyono announced a sharp rollback of subsidies in September 2005 with more than doubled the retail price of gasoline and diesel. The subsidy reduction is likely to temper the rapid increases in oil demand seen in recent years and can augment Indonesia's dwindling energy supplies. This goal has stimulated promoting energy efficiency and the usage of sustainable, renewable and non-polluting energy resources capable of simultaneously balancing economic and social development with environmental protection [5,7]. These resources include alternative energy such as hydro, wind and biofuels. Biofuels are simple to use, biodegradable, and essentially free of sulfur and aromatics. Recently, biodiesel as an alternative fuel has been found to be more attractive in various energy sectors especially in the transportation sector [8]. Biodiesel has an immense potentiality to be a part of a sustainable energy mix in the future [9]. The demand for biodiesel in European countries is expected to be up to 10.5 billion L by 2010 [10]. Globally, annual biodiesel production increased from 15,000 barrel per day in 2000 to 289,000 barrel per day in 2008 as shown in Fig. 9. In Indonesia, annual biodiesel production increased from 14.5 thousand barrel per day in 2008 to 16.2 thousand barrel per day in 2009 at an average annual increase of 11.7% as shown in Fig. 10. It is expected that biodiesel production will increase substantially in Indonesia in the near future due to the availability of bulk biodiesel feedstock such as palm oil and *Jatropha curcas*.

2. Biodiesel as a potential renewable energy resource

The technical regulation of biodiesel and specification are set by the European Union as EN 14214 or by USA as ASTM 6751-

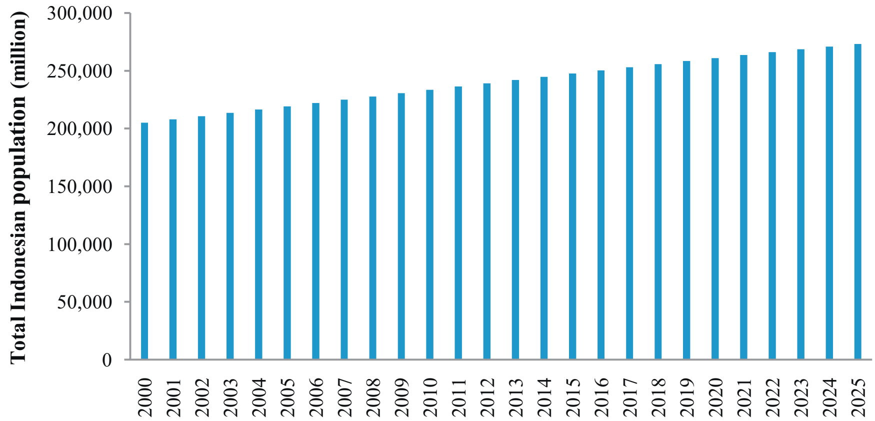

Fig. 1. Total Indonesia population of the world (million) from 2000 to 2050.

Source: [1].

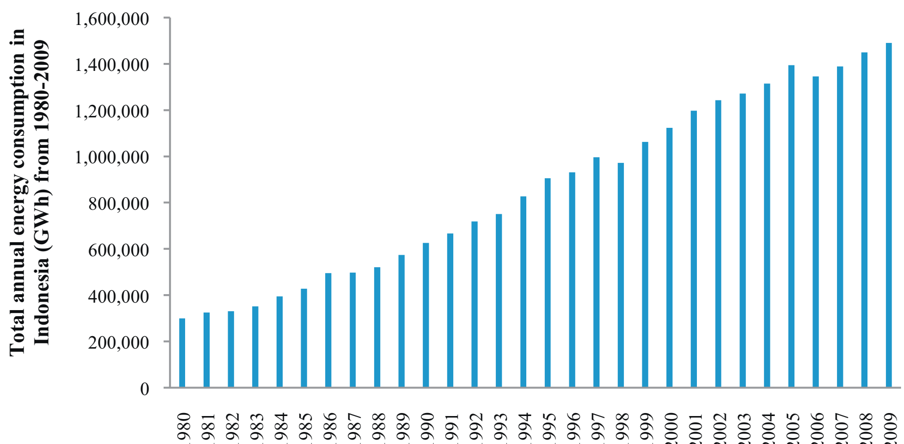

Fig. 2. Total annual energy consumption in Indonesia from 1980 to 2009 (GWh).

Source: [2].

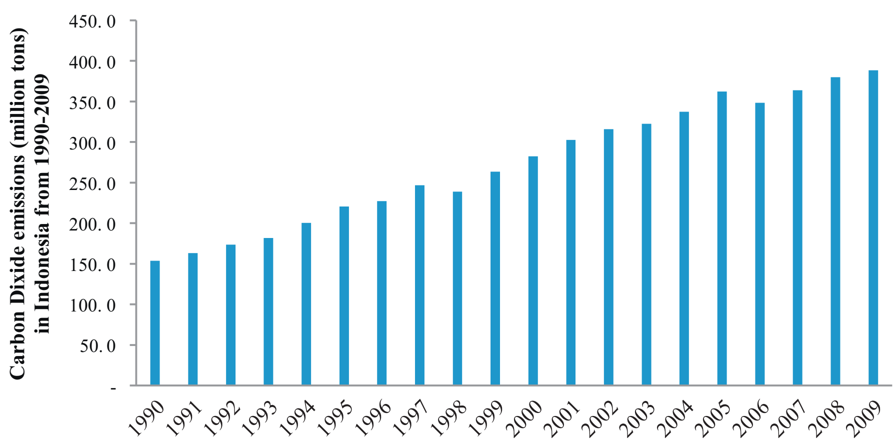

Fig. 3. Carbon dioxide emissions production in Indonesia (million tons) from 1990 to 2009.

Source: [2].

Table 1
Reserve and life time of fossils fuels in Indonesia.

Type of energy	Reserve energy	Life time (years)
Oil	4.7 billion barrel	15
Gas	90,300 billion cubic feet	35
Coal	4.968 billion ton	61

Source of data: [6].

02. Biodiesel is monoalkyl esters of long chain fatty acids derived from vegetable oils (both edible and non-edible) or animal fats [13,14]. Biodiesel is biodegradable, non-toxic and environmentally friendly as compared to petro diesel and can be run in diesel engine with same or better performance as compared to normal diesel fuel. There are four different methods of producing biodiesel from vegetable oils. These methods include pyrolysis/cracking, dilution with hydrocarbons blending, emulsification, and transesterifica-

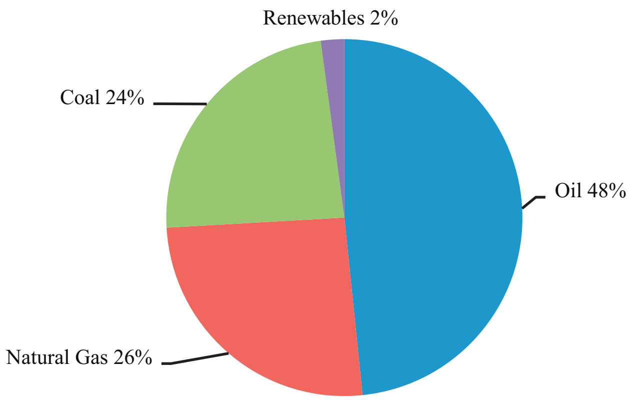

Fig. 4. Statistics of Indonesia energy consumption by fuel in 2009.
Source: [2].

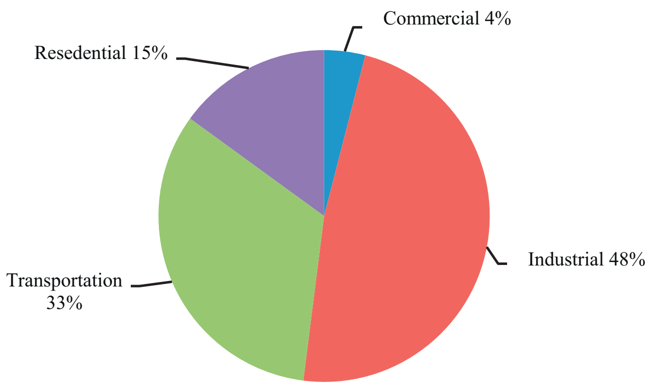

Fig. 5. Statistics of Indonesia energy consumption by sector in 2007.
Source: [4].

tion [7,15–18]. Transesterification seems to be the best method among other approaches. This process turns the oils into esters, separating out the glycerine. The glycerine sinks to the bottom and the biodiesel floats on top and can be siphoned off. One hundred pounds of fat or oil are reacted with 10 pounds of a short chain alcohol in the presence of a catalyst to produce 10 pounds of glycerin and 100 pounds of biodiesel. As per the transesterification reaction, 3 mol of methanol were required to react with the vegetable oil as shown in Fig. 11. The most commonly used process is the catalytic transesterification process. There are three methods of catalytic transesterification that can be used; alkalin catalysts such as sodium hydroxide (NaOH) or potassium hydroxide (KOH), acid catalysts such as sulfuric acid, hydrochloric acid and sulfonic acid and enzymes such as Diazomethane CH_2N_2. Many researchers have found that alkali catalytic methods are the fastest and most economical than other catalytic reactions [15,19–21]. However, acid-catalyzed reaction gives very high yield in esters. In this reaction, glycerol is an important by-product and can be burned for heat or be used as feedstock in the cosmetic industry [22]. Fig. 12 shows basic scheme for biodiesel production.

The use of vegetable oils as alternative fuels has been around since 1900 when the inventor of the diesel engine, Rudolph Diesel first tested peanut oil in his compression ignition engine. However, due to cheap petroleum products such non-conventional fuels never took off until recently. Biodiesel is already being used in USA and Europe to reduce air pollution, and reduce dependence on depleting fossil fuel localized in specific regions of the world and increases in crude oil prices [30].

Biodiesel contains no petroleum products, but it is compatible with conventional diesel and can be blended in any proportion with fossil-based diesel to create a stable biodiesel blend. Therefore, biodiesel has become one of the most common types of biofuels in the world. The key milestones in the development of biodiesel industry are shown in Table 2.

2.1. Biodiesel feedstocks

The wide range of available feedstocks for biodiesel production represents one of the most important advantages of producing biodiesel as an alternative energy resource [32].There are more than 350 oil-bearing crops identified, among which only soybean, palm, sunflower, safflower, cottonseed, rapeseed and peanut oils are considered as potential alternative fuels [30,33]. However, some other non-edible oils such as *jatropha*, *karanja* and *neem* are gaining worldwide attention. Fig. 13 shows some main biodiesel feedstocks. The availability of feedstocks for producing biodiesel depends on the geographical locations and agricultural practices of the country. Therefore, selecting the best feedstock is vital to ensure low production cost of biodiesel. From literature, it has been found that feedstock alone represents more than 75% of the overall biodiesel production cost as shown in Fig. 14. In general, biodiesel feedstock can be divided into four main categories as below [34]:

(1) Edible vegetable oil: rapeseed, soybean, sunflower, palm and coconut oil.
(2) Non-edible vegetable oil: *jatropha*, *karanja*, sea mango, algae and halophytes.

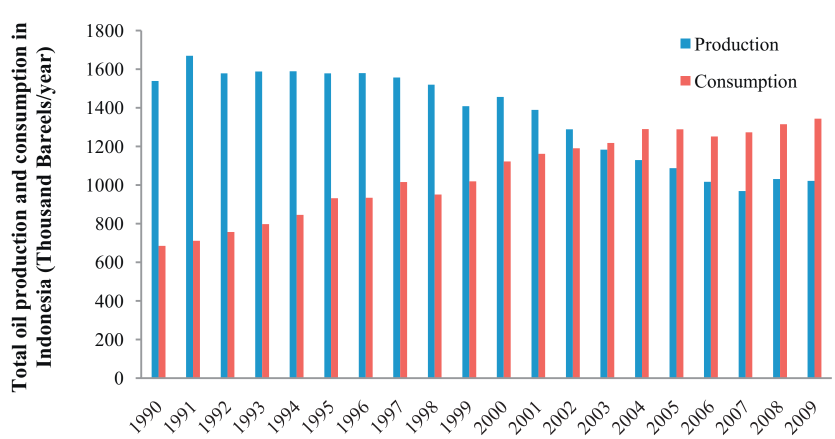

Fig. 6. Total annual Indonesia's oil production and consumption (Thousand barrels/year) from 1990 to 2009.
Source: [2].

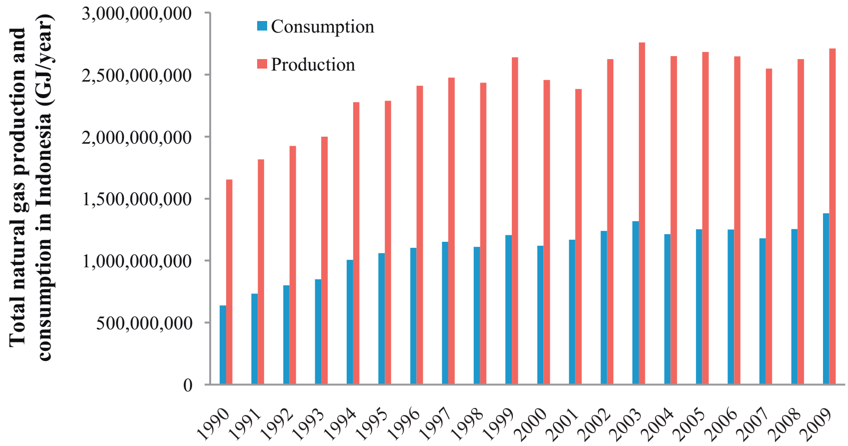

Fig. 7. Total annual Indonesia's natural gas production and consumption (GJ/year) from 1990 to 2009.

Source: [2].

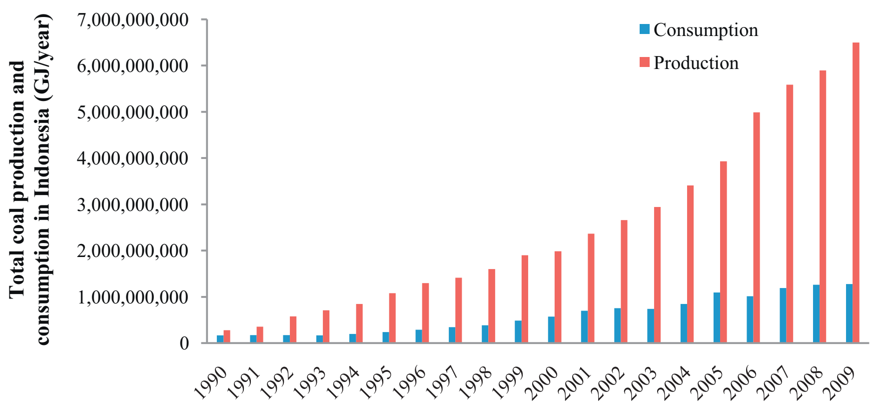

Fig. 8. Total annual Indonesia's coal production and consumption (GJ/year) from 1990 to 2009.

Source: [2].

(3) Waste or recycled oil.
(4) Animal fats: tallow, yellow grease, chicken fat and by-products from fish oil.

In Indonesia, the most two available feedstocks for biodiesel production are palm oil and *J. curcas*. Table 3 shows the palm oil and *J. curcas* plantation development plan between 2007 and 2010 released by the Ministry of Agriculture. Production of biodiesel from these resources has a potential to become a significant industry in Indonesia [36]. In terms of revenue, production of Crude Palm Oil (CPO) and Crude *J. curcas* Oil (CJCO) provides Indonesia with its biggest non-petroleum source of biodiesel, and this is expected to grow in the future. Beyond revenue generation, *J. curcas* plantations also currently provide a livelihood for many Indonesian families. Table 4 shows a summary of projection on biodiesel development from CPO and CJCO up to 2010.

Indonesia is in a strong position to further develop CJCO production into a much larger and more profitable biodiesel industry. While Indonesia has a great potential to become a major world player in biodiesel, it is unlikely to be fulfilled, unless sustain-

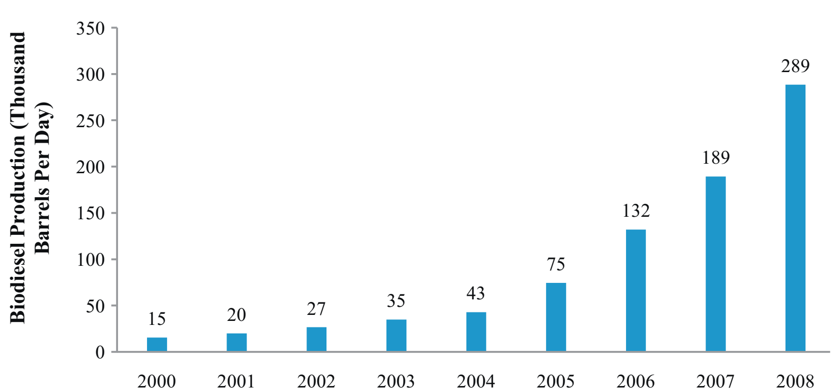

Fig. 9. Total world biodiesel productions (Thousand Barrels Per Day) between 2000 and 2008.

Source: [11].

Table 2
Key milestones in the development of biodiesel industry.

Date	Event
August 10, 1893	Rudolf Diesel's prime diesel engine model, which was fueled by peanut oil, ran on its own power for the first time in Augsburg, Germany
1900	Rudolf Diesel showed his engine at the word exhibition at the world exhibition in Paris, his engine was running on 100% peanut oil
August 31, 1937	A Belgian scientist, G. Chavane was granted a patent for a "Procedure for the transformation of vegetable oils for their uses as fuels. The concept of what is known as "biodiesel" today was proposed for the first time
1977	A Brazilian scientist, Expedito Parente, applied for the first patent of the industrial process for biodiesel
1979	Research into the used of transesterified sunflower oil and refining it to diesel fuel standards, was initiated in South Africa
1983	The process for producing fuel-quality, engine-tested biodiesel was completed and published internationally
November, 1987	An Austrian company, An Austrian company, Gaskoks established the first biodiesel pilot plant
April, 1989	Gaskoks established the first industrial-scale plant
1991	Austria's first biodiesel standard was issued
1997	A German standard, DIN 51606, was formalized
2002	ASTM D6751 was first published
October, 2003	A new Europe-wide biodiesel standard, DIN EN 14214 was published
September, 2005	Minnestosa became the first US state to mandate that all diesel fueled sold in the state contain part biodiesel, requiring a content of at least 2% biodiesel
October, 2008	ASTM published new Biodiesel Blend Specification Standards
November, 2008	The current version of the European Standard EN 14214 was published and supersedes EN 14214:2003

Source of data: [25].

able plantation practices are followed. The combination of a rich natural resource base, dedicated and knowledgeable people and recent advances in biodiesel technology, will form a strong base that makes Indonesia a major world player in biodiesel [39].

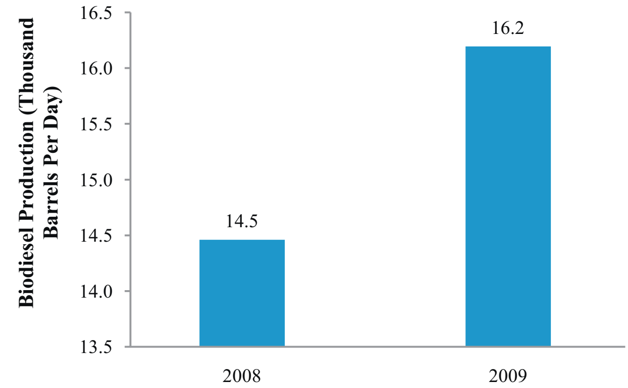

Fig. 10. Total Indonesian biodiesel production (Thousand Barrels Per Day) in 2008 and 2009, respectively.
Source: [12].

2.2. Biodiesel policies and standards

Globally, there are many biofuel policies which have been set recently by many countries around the world. All these policies have promoted using biodiesel fuels in their energy mix and set the target for future biodiesel consumption. Table 5 shows a summary of some biodiesel targets in some selected countries around the world.

Table 4
Projection on biodiesel development in Indonesia up to 2010.

Parameter	Unit	Biodiesel material	
		CPO	CJCO
Land	ha	1,500,000	1,500,000
Direct employment	Worker	750,000	500,000
Biodiesel	Ton oil	6,000,000	2,250,000
Revenue/worker (CPO @ 2 ha and *Jatropha* @ 3 ha)	Rp/year/worker[a]	20,000,000	13,500,000
Industry	Unit	167	22,727

Source of data: [38].
[a] 1 USD = 9000 IDR.

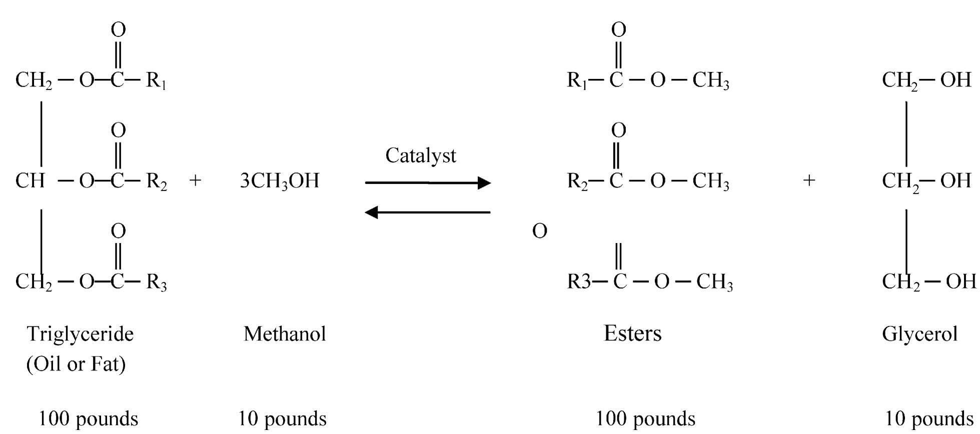

Fig. 11. Equation of transesterification reaction.

Source: [15,18–20,23–29].

Table 3
Plantation development plan 2007–2010 (in ha).

No.	Plantation	2007	2008	2009	2010	Total
1	Palm oil	473,265	473,265	473,265	473,265	1,893,060
2	*Jatropha curcas*	341,000	345,000	360,000	375,000	1,461,000

Source of data: [37].

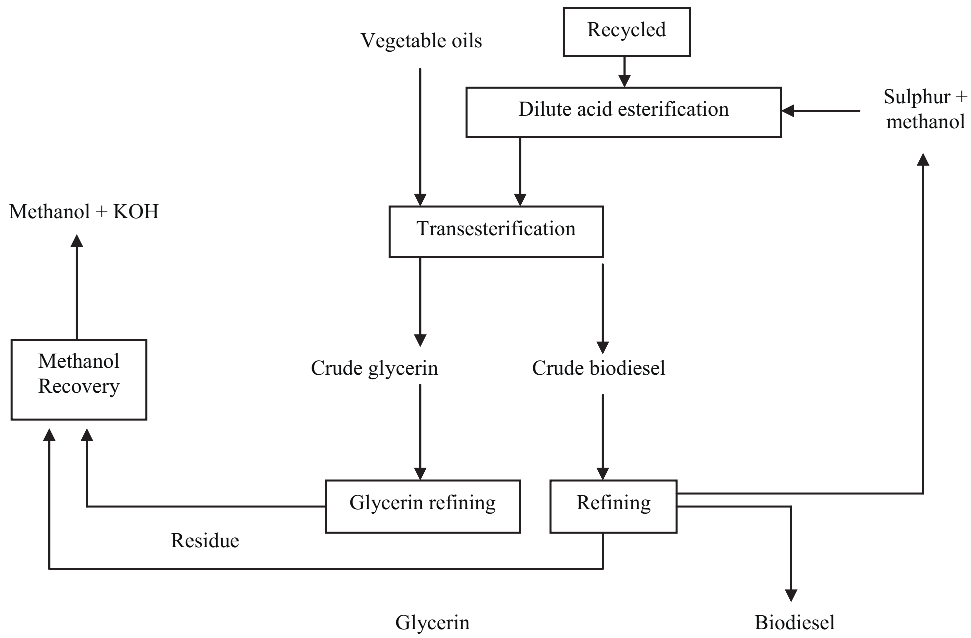

Fig. 12. Basic schemes for biodiesel production.

Source: [20,31].

The effort of biodiesel development in Indonesia has been made since more than 10 years ago. However, the activity was not given a priority due to the cheap oil price in the country at that time. Research activity was limited only in laboratory scale, production process technology, biodiesel property, performance test, standardization and promotion of biodiesel. Several Indonesian research institutions have been pioneering worked on biodiesel development including Lemigas (Oil and Gas Technology), PPKS Medan (Indonesian Oil Palm Research Institute, Department of Agriculture), ITB (Bandung Institute of Technology), and BPPT (Agency for the Assessment and Application of Technology) [37].

The government of Indonesia announced in 2006 the National Energy Policy (NEP). This policy targets jobs creation for 3.5 million people, increased income for 3.5 million people on-farm and off-farm, development of 5.25 mha of biofuel cropland (1.5 mha palm, 1.5 mha *J. curcas*, 1.5 mha cassava, 750,000 ha sugarcane) on currently uncultivated land, production of 62.000 kL of biodiesel from palm oil (equivalent to 62.000 tons), production of 7.5 million tons of *J. curcas* oil in 2010 and 15 million tons in 2015 on 3 mha of arable land and development of biofuel market as an emergency measure against poverty and unemployment from 2006 to 2025 [53]. Fig. 15 shows biodiesel development roadmap. The policy also aims to fulfill an increase of biodiesel blend of total diesel consumption from 10% in 2010 to 20% in 2025 as shown in Fig. 16 [35,54–58].

Table 5
Summary of worldwide biodiesel targets.

Country	Official biodiesel targets
EU	Using 2% in 2005 and increasing in stages to a minimum of 5.75% by the end of 2010 and 20% by 2020
Japan	5% blend for biodiesel by 2010
Malaysia	Processed palm oil blend of 5%
Philippines	Coconut blend of 2% by 2009
Thailand	5% (B5) mix in 2007, 10% (B10) by 2011 and production of 8.5 million L per day by 2012
Brazil	Minimum blending of 3% biodiesel to diesel by July 2008 and 5% (B5) by end of 2010.
Canada	2% renewable content in diesel fuel by 2012
India	Meet 20% of the diesel demand beginning with 2011–2012
Taiwan	Directly subsidies or other tax exemptions (e.g., excise tax) for biodiesel
China	Tax exemption for biodiesel produced from animal fat or vegetable oil

Source of data: [10,28,35,36,40–52].

The European Standard for biodiesel (EN 14214) and the American Standard Specification for biodiesel (ASTM 6751-02) are the two major international biodiesel standards followed all over the world where the characteristics and qualities of biodiesel such as the flash point, kinematic viscosity, specific gravity, free fatty acids and acid value have been introduced [60,61]. Table 6 shows detailed ASTM D 6751 and EN 14214 biodiesel specifications.

In February 2006, the biodiesel standard SNI 04-7182-2006 has been approved by the National Standardization Agency (BSN) through a decree No. 73/KEP/BSN/2006 [37]. This standard has aimed to protect biodiesel consumers, producers and to support the development of local biodiesel industries. It has been formulated by a technical committee consisting of all related biodiesel stakeholder such as government institutions, private institutions and academicians. The content of SNI 04-7182-2006 has partially adopted the existing European and US standard. The details SNI 04-7182-2006 standards are shown in Table 7.

2.3. Advantages and disadvantages of biodiesel

The following table (Table 8) summarizes the advantages and disadvantages of using biodiesel as substitute of diesel.

2.4. Sustainability of biodiesel

The concept of sustainable development was included in the 1987 report published by the United Nations Commission for the Environment, titled Our Common Future, coordinated by Gro Harlem Brundtland. In this report, sustainable development was explained as meeting the necessities of the present generation without compromising the future generation's needs. The growing interest for expanding the production of biofuels on a global scale beside the scarcity of conventional fossil fuels, their growing emissions of pollutants, their increasing costs and the need to establish sustainability and certification criteria of biodiesel has been identified globally [63,72].

Fig. 13. Main biodiesel feedstock.

Source: [35].

Biodiesel are perceived to be a pathway out of poverty' for developing countries. Moreover, biodiesel may provide new incentives for investments in agricultural research and development, offer farmers source of income [73], and stimulate linkages to food markets that currently do not exist [74]. Use of biodiesel can make any nation self-dependent to some extent, but still it is far behind to make a significant difference in import of crude oil, which is the need of the present days.

The sustainability principles of biodiesel were primarily derived from existing principles developed by the Roundtable on Sustainable Biofuels (RSB). Sum of these principles are as follows [75,76]:

(1) Biodiesel shall contribute to climate change mitigation by significantly reducing lifecycle greenhouse gas emissions as compared to fossil fuels. Producers shall strive to continuously improve that reduction.
(2) Biodiesel production shall support human and labor rights and shall ensure safe and decent working conditions.
(3) Biodiesel production shall contribute to the social and economic development of local communities.
(4) Biodiesel production shall strive to improve food security.
(5) Throughout the supply chain, the biodiesel industry shall implement management systems that maintain and strive to

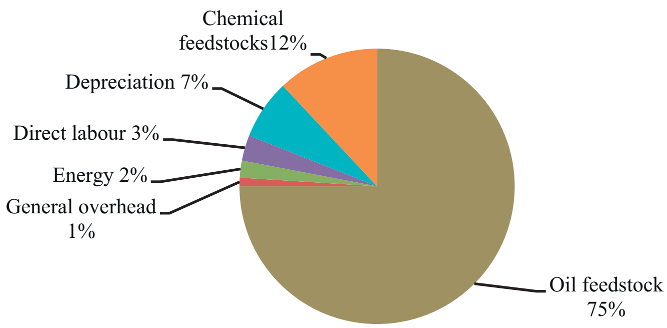

Fig. 14. General cost breakdown for production of biodiesel.
Source: [16,34].

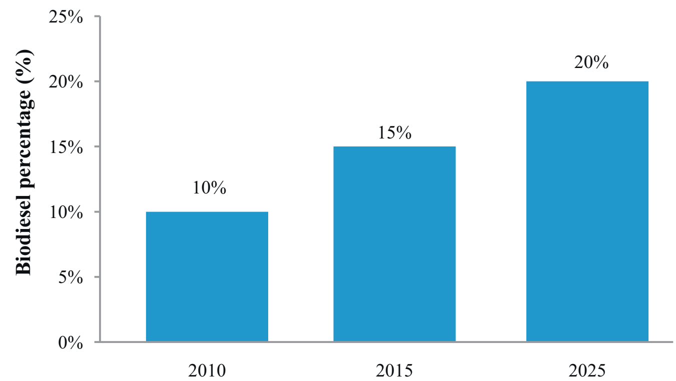

Fig. 16. Indonesia's biodiesel target between 2010 and 2025.
Source: [35,54–58].

improve biodiversity, areas of high conservation value, and the quality of natural resources such as soil, air, and water.

(6) Biodiesel production shall respect natural resource rights, such as land and water rights.
(7) Biodiesel production shall avoid negative impacts on biodiversity, ecosystems, and areas of high conservation value.

Achten et al. [77] performed a qualitative evaluation of the future sustainability of cultivating *Jatropha*, focusing on the environmental, social and economical aspects; they determined that the cultivation is sustainable when practiced in marginal or degraded lands, but not when fertile areas are dedicated, which could serve to cultivate foodstuffs or other crops with greater profitability.

2.5. Projected biodiesel consumption in Indonesia

According to Indonesia's Ministry of Energy and Mineral Resources, 520,000 tons of biodiesel were produced in 2007, equivalent to 590,000 kL. Based on Indonesia's projection of achieving 2.41 million kL by 2010, the country has achieved 24.4% of its objec-

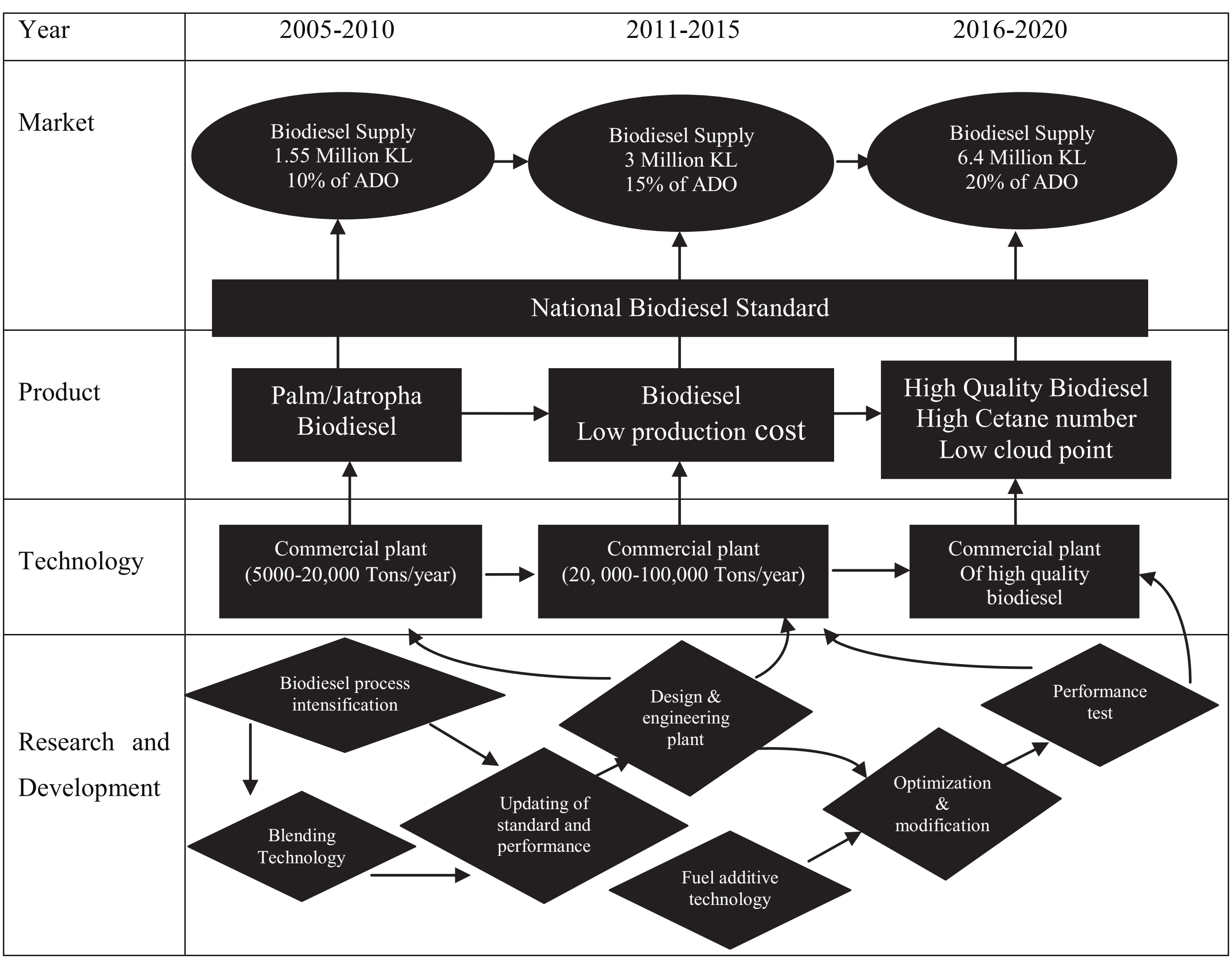

Fig. 15. Biodiesel Development Roadmap in Indonesia.
Source: [37,59].

Table 6
ASTM D 6751–02 and EN 14214 specification for biodiesel B100.

Properties	ASTM D 6751		EN 14214	
	Limit	Method	Limit	Method
Density at 15 °C	870–890 kg/m^3	ASTM D4052-91	860–900 kg/m^3	EN ISO 3675, EN ISO 12185
Flash point	130 °C minimum	ASTM D93	>101 °C (minimum)	EN ISO 3679
Viscosity @ 40 °C	1.9–6.0 mm^2/s	ASTM D445	3.5–5.0 mm^2/s	EN ISO 3140
Sulfated ash	0.020% m/m maximum	ASTM D874	0.02% m/m (maximum)	EN ISO 3987
Cloud point	Report to customer	ASTM D2500	Based on national specification	EN ISO 23015
Copper strip corrosion	Class 3 maximum	ASTM D130	Class 1 rating	EN ISO 2160
Cetane number	47 (minimum)	ASTM D613	51(minimum)	EN ISO 5165
Water content and sediment	0.050 (%v) maximum	ASTM D2709	500 mg/kg (maximum)	EN ISO 12937
Acid number	0.50 mg KOH/g maximum	ASTM D664	0.50 mg KOH/g (maximum)	EN 14104
Free glycerin	0.02% (m/m) maximum	ASTM D6584	0.02% (m/m) (maximum)	EN 1405/14016
Total glycerol	0.24% (m/m) maximum	ASTM D6548	0.25% (m/m)	EN 14105
Methanol content	0.20% (m/m) maximum	EN 14110	0.20% (m/m) (maximum)	EN 14110
Phosphorus	10 mg/kg maximum	ASTM D4951	10.0 mg/kg (maximum)	EN 14107
Distilation temperature	360 °C	ASTM D1160	–	–
Sodium and Potassium	5.00 ppm maximum	EN 14538	5.00 mg/kg (maximum)	EN 14108, EN 14109
Oxidation stability	3 h minimum	EN ISO 14112	6 h (minimum)	EN ISO 14112
Carbon Residue	0.05 maximum wt%	ASTM D 4530	0.30%(m/m) (maximum)	EN OSO 10370
Calcium and Magnesium	5 ppm maximum	EN 14538	5 ppm (maximum)	EN 14538
Iodine number	–	–	120 giod/100 g (maximum)	EN 14111

Source of data: [15,23,25,28,32,35,52,62–65].

tive. Currently, there are eight biodiesel plants in Indonesia. By 2011 there will be another 15–17 more, adding 2 million kL of biodiesel production [58]. In this review, the projected biodiesel consumption in Indonesia's transportation and industrial sector between 2005 and 2010 has been collected and presented in the following subsection.

2.5.1. Transportation sector

Renewable energy policy for the transportation sector stated that the target of biodiesel use in 2010 is 10% of the total diesel oil [78]. Table 9 shows the potential biodiesel substitution for the transportation sector between 2005 and 2010.

2.5.2. Industrial sector

In industrial sector, renewable energy policy is not restricted to the blending regulation of 10%. Thus, pure biodiesel can be also marketed without any trade limit as shown in Table 10. In July 2006, Department of Energy and Mineral Resources released the price of industrial diesel fuel to be in the range of IDR 6014.91 to IDR 6227.27/L [78]. Meanwhile, the price of crude palm oil (CPO) per liter is about IDR 3628 per January 2006, and the real potential price can reach IDR 4000/kg. The price of processing CPO to produce biodiesel is approximately IDR 1500.00/L for any plant with annual production capacity of 500 tons and at IDR 550.00/L for a plant with annual production capacity of 120,000 tons. Therefore, the price of CPO is around IDR 3800/L and price of biodiesel for industrial sectors is between IDR 4300 and IDR 5300/L [37].

3. Feasibility of *Jatropha curcas* as a biodiesel in Indonesia

3.1. Botanical description of Jatropha curcas

J. curcas L. is a small or large shrub tree, up to 5–7 m tall, belonging to the *Euphorbiaceae* family [16,21,27,53,79–86] which consists of around 800 species, which in turn belong to some 321 genera. Within this family, the plants of major economic significance include [87]:

Table 7
The detail SNI 04-7182-2006 characteristic comparisons of fossil diesel fuel (FDF) and biodiesel.

No.	Parameter	Unit	FDF	Biodiesel
1	Density	kg/m^3	820–870 (15 °C)	850–890 (40 °C)
2	Kinematic viscosity (40 °C)	Mm^2/s (cSt)	1.6–5.8	2.3–6.0
3	Cetane number	–	Min. 45	Min. 51
4	Flash point	°C	Min. 60	Min. 100
5	Cloud point	°C	–	Max. 18
6	Pour point	°C	Max. 18	–
7	Copper strip corrosion	Rating (3 h at 50 °C)	Max. no 1	Max. no 3
8	Carbon residue—in undistilled sample, or—in 10% distillation residue	% (m/m)	–	Max 0.05
		% (m/m)	Max. 0.1	Max. 0.30
9	Water and sediment	%-vol.	Max. 0.05	Max. 0.05
10	90% (v/v) recovered at distillation temperature	°C	–	Max. 360
11	95% (v/v) recovered at distillation temperature	°C	Max. 370	–
12	Sulfated ash	% (m/m)	Max. 0.01	Max. 0.02
13	Sulfur content	ppm-m (mg/kg)	Max. 5000	Min. 0.001[a]
14	Phosphorous content	ppm-m (mg/kg)	–	Max. 10
15	Acid number	mg-KOH/g	max.0.6	–
16	Free glycerol	% (m/m)	–	Max. 0.02
17	Total glycerol	% (m/m)	–	Max. 0.24
18	Ester content	% (m/m)	–	Min. 96.5
19	Iodine number	% (m/m) (g-I2/100 g)	–	Max. 115

Source of data: [28,37].
[a] (% mass).

Table 8
Summary of advantages and disadvantages of biodiesel.

Advantages	Disadvantages
Portability, availability and renewability of biodiesel.	
Biodiesel emits fewer emissions such as CO_2, CO, SO_2, PM and HC compared to diesel.	It emits Higher NO_x emission than diesel.
Producing biodiesel is easier than diesel and is less time consuming.	Higher pour and cloud point fuel freezing in cold weather causing a cold weather starting.
Biodiesel can make the vehicle perform better as it has a cetane number of over 100. Moreover, it prolongs engine life and reduces the need for maintenance (biodiesel has better lubricating qualities than fossil diesel).	Biodiesel has a corrosive nature against copper and brass.
Owing to the clarity and the purity of biodiesel, it can be used without adding additional lubricant unlike diesel engine.	The high viscosity (about 11–17 times greater than diesel fuel) due to the large molecular mass and chemical structure of vegetable oils leads to problems in pumping, combustion and atomization in the injector systems of a diesel engine.
Biodiesel hold a great potential for stimulating sustainable rural development and a solution for energy security issue.	Biodiesel lower engine speed and power. The biodiesels on the average decrease power by 5% compared to that of diesel at rated load
Biodiesel does not need to be drilled, transported, or refined like diesel.	degradation of biodiesel under storage for prolonged periods
Biodiesel is more cost efficient then diesel because it is produced locally.	Coking of injectors on piston and head of engine.
Biodiesel is better than diesel fuel in terms of sulfur content, flash point, aromatic content and biodegradability.	The high viscosity, in long term operation introduces the development of gumming, formation of injector deposits, plugging of filters, lines and injectors, ring sticking as well as incompatibility with conventional lubricating oils.
It is safer to handle, being less toxic, more biodegradable, and having a higher flash point.	Carbon deposits on piston and head of engine.
Non-flammable and non-toxic, reduces tailpipe emissions, visible smoke and noxious fumes and odors.	Biodiesel causes excessive engine wear.
No required engine modification up to B_{20}.	Biodiesel is not cost-competitive with gasoline or diesel.
Higher combustion efficiency.	Low volatility of biodiesel.

Source of data: [8,15,17,24,25,29,32,41,63,65–71].

Table 9
Potential biodiesel substitution for the transportation sector between 2005 and 2010.

Year	Automotive diesel oil (thousand kL)	Biodiesel (thousand kL)	Total (thousand kL)
2005	11,791	0	11,791
2006	14,411	87	14,498
2007	12,669	167	12,836
2008	13,101	377	13,478
2009	12,949	1203	14,152
2010	13,522	1377	14,899

Source of data: [37,78].

- Roots: *manihot esculenta* (cassava)
- Rubber: *hevea brasiliensis*
- Nuts: *caryodendron orinocense* (*tacay* nut)
- Vegetables: *sauropus androgynus* (*katuk*)
- Oils: *ricinus communis linn* (castor bean); *aleurites* spp. (*tung* trees)
- *Sapium sebiferum* (Chinese tallow tree); *J. curcas* Linn.
- Physic nut
- Hydrocarbon: *euphorbia* spp.
- Medical: *croton* spp.; *jatropha* spp.

Jatropha is a drought resistant crop that has a life expectancy of up to 50 years [16,53,84–86,88–90]. It is also known as Ratanjayot and physic nut [17,21,82,89]. It can grow in arid, semiarid and wastelands [90,91]. The plant has its native distributional range in Mexico, Central America, Africa, Brazil, Indian subcontinent, Peru, Argentina and Paraguay, although nowadays it has a pan tropical distribution with distinct JCL seed provenances. In Indonesia, it can be produced in most parts especially in the dry south eastern part of Nusa Tenggara Islands [16,70,82,85,88,89].

The plant develops a deep taproot and initially four shallow lateral roots. The taproot may stabilize the soil against landslides while the shallow roots are alleged to prevent and control soil erosion caused by wind or water, but this potential has not been investigated scientifically. The leaves are smooth, 4–6 lobed and 10–15 cm in length and width. The plant is monoecious and the terminal inflorescences contain unisexual flowers. The ratio of male to female flowers ranges from 13:1 to 29:1 and decreases with the age of the plant. Normally JCL flowers only once a year during the rainy season. In permanently humid regions or under irrigated conditions JCL flowers almost throughout the year. The blackish seeds of most provenances contain toxins, such as phorbol esters, curcin, trypsin inhibitors, lectins and phy-tates, to such levels that the seeds, oil and seed cake are not edible without detoxification [80,92,93].

J. curcas can grow under a wide range of rainfall regimes from 250 to over 1200 mm per annum [81,94]. The temperature for the growth is 20–26 °C, this plant also can adapt to fertile soil, good drainage, not stagnant, and pH from 5.0 to 6.5 [6]. The plant of *J. curcas* grows on well-drained soils with good aeration and is a well adapted to marginal soil with low nutrient content shedding the leaves in dry season [79,81]. It was reported that, plantation spaces of 2 m × 2 m, 2.5 m × 2.5 m, and 3 m × 3 m are reported to be satisfactory and give larger yields of fruit [85]. It bears fruits from the second year of its establishment, and the eco-

Table 10
Projected biodiesel consumption for industrial sector up to 2010 with various blending percentage (Thousand kL).

Year	Diesel oil for industry	10%		20%		30%		40%	
		Biodiesel	Fossils	Biodiesel	Fossils	Biodiesel	Fossils	Biodiesel	Fossils
2005	8320	832	7488	1644	6656	2496	5824	3328	4992
2006	8570	857	7713	1714	6856	2571	5999	3428	5142
2007	8827	883	7944	1765	7062	2648	6179	3531	5296
2008	9901	909	8182	1818	7263	2727	6366	3636	5455
2009	9364	936	8428	1873	7491	2809	6555	3746	5618
2010	9645	965	8681	1929	7716	2894	6752	3858	5787

Source of data: [37,78].

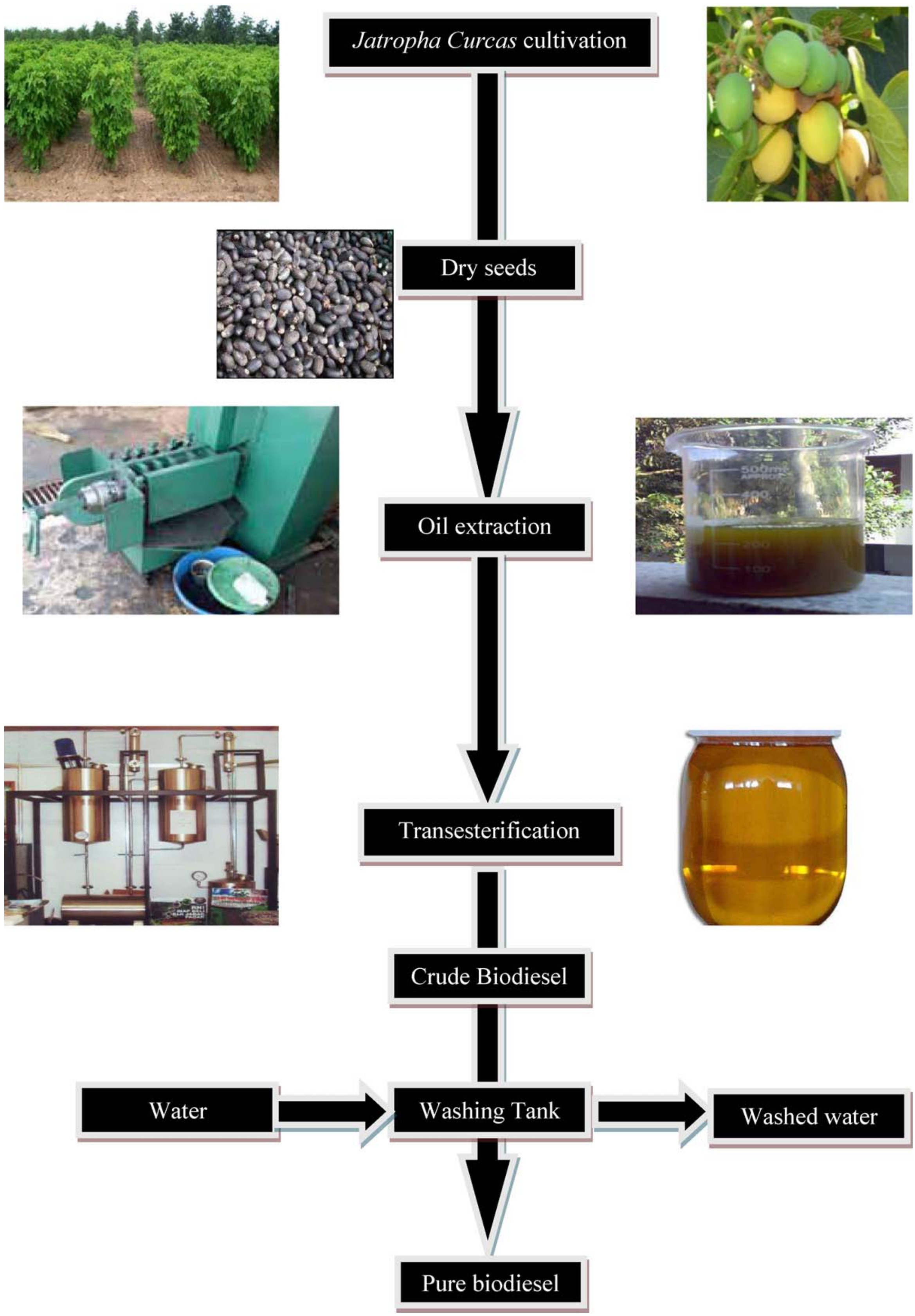

Fig. 17. *Jatropha curcas* biodiesel production chain.

Source: [21,77].

nomic yield stabilizes from the fourth or fifth year onwards. The fruit is a kernel which contains three seeds each. It gives about 2–4 kg/seed/tree/year. In poor soils, the yields have been reported to be about 1 kg/seed/tree/year [95]. The oil yields of *J. curcas* is reported to be 1590 kg/ha [17,84,96,97].

3.2. Benefits and advantages of Jatropha curcas

J. curcas offers many benefits. Some of these benefits include [10,69,80,86,98–100]:

- It costs almost nothing to grow.
- It is perennial, drought resistant and adapted for marginal land and seems to be adequate for land reclamation.
- It can be grown almost anywhere—even in sandy, saline, or otherwise infertile soil.
- It is easy to propagate (a cutting simply pushed into the ground will take root).
- It is capable of stabilizing sand dunes, acting as a windbreak, and combating desertification.
- It naturally repels both animals and insects.
- It does not exhaust the nutrients in the land.
- It does not require expensive crop rotation.
- It does not require fertilizers.
- It grows quickly and establishes itself easily.
- It has a high yield (*Jatropha* can yield about 1000 barrels of oil per year per square mile—oil content of the seed is 55–60%).
- No displacement of food crops is necessary.
- It is great for developing countries in terms of energy and jobs creation.
- The biodiesel byproduct, glycerine, is profitable in itself.
- The waste plant mass after oil extraction can be used as a fertilizer.
- The plant recycles 100% of the CO_2 emissions produced by burning the biodiesel.
- The plant can be used as a hedge to prevent and control erosion and to reclaim land.
- The oil is being extensively used for making soap in some countries because it has a very high saponification value.
- The oil is used as an illuminant as it burns without emitting smoke.
- The latex of *J. curcas* contains an alkaloid known as "*jatrophine*" which is believed to have anti-cancerous properties.
- From the bark of *J. curcas* a dark blue dye is produced which is used for coloring cloth, fishing nets etc.
- The byproduct of *J. curcas* seeds contain high nitrogen, phosphorous and potassium which is used for fish foods, domestic animals food and in lands as fertilizer.
- Its cake can be used to generate biogas that could be used locally as household cooking fuel.

3.3. Production and applications of Jatropha curcas

Currently, *J. curcas* can produce 2000 L/ha oil annually [101]. JCL oil is mainly transesterified to (m)ethyl esters (biodiesel) and glycerol as previously shown in Fig. 11 [22]. Fig. 17 shows *J. curcas* biodiesel production chain. At the present, the production and usage of *J. curcas* oil is no longer confined to a specific geographic region or a limited number of end-products. Large quantities of *J. curcas* oil are consumed all over the world, as ingredients of numerous products manufactured by a large number of industries. *J. curcas* was found to be suitable as a non-edible vegetable oil feedstock in oleochemical industries (biodiesel, fatty acids, soap, cosmetics, paraffin, fatty nitrogenous derivatives, surfactants and detergents, etc.) [21,101,102]. To supply *J. curcas* oil and its derived ingredients to these industries and their customers, an integrated, *J. curcas* oil

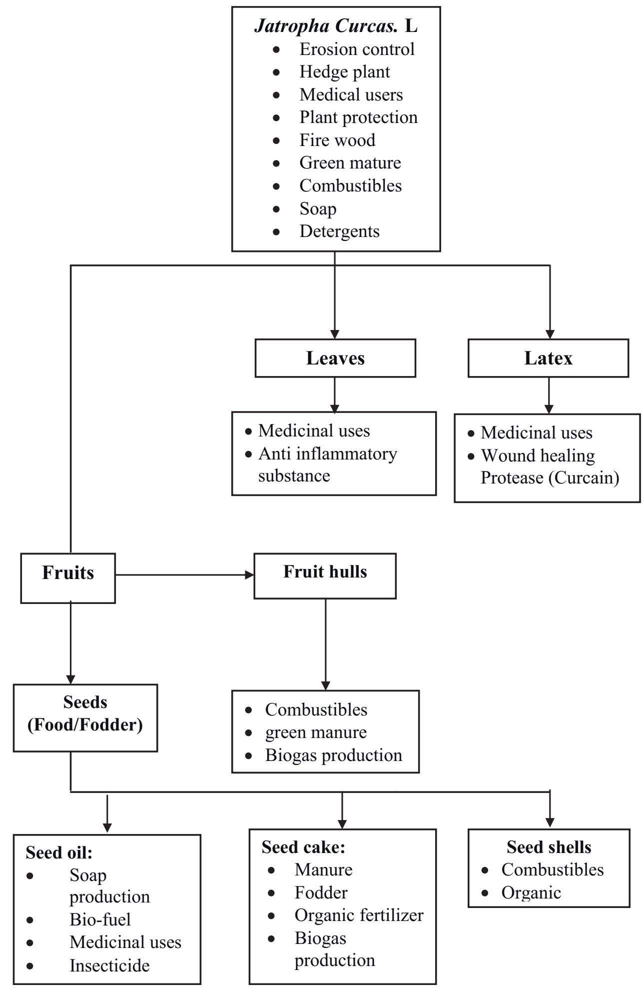

Fig. 18. Some important usages of *Jatropha curcas*.
Source: [86,87,103].

production has been developed over the years [87]. Fig. 18 highlights some important usages of *J. curcas*.

In many communities, *J. curcas* plant has been found to be suitable for using in different aspects. It is commonly grown in Indonesia as a live hedge around agricultural fields as it is not browsed by goats or cattle. Moreover, it can be cut or lopped at any desired height. Apart from using *J. curcas* oil as a biodiesel, the oil can also be used to produce soap and biocides (insecticide, molluscicide, fungicide and nematicide) [103]. Based on different local literatures, some of the economic activities through the use of *J. curcas* are summarized in Table 11.

3.4. Properties and qualities of Jatropha curcas

The characteristics of crude *J. curcas* oil (CJCO) vary depending on the geographical place in which it has been grown. The maximum amount of oil that can be extracted from a given sample of the seed depends on the quality of feedstock and the method of extraction. Oil content of *J. curcas* kernel was found higher than linseed, soybean, and palm kernel, which are 33.33%, 18.35% and 44.6%, respectively, [107] where the oil content of *J. curcas* kernel was determined at 63.16% and 66.4% in some other references [102,108].

The parameters which are selected and established to define the quality of biodiesel can be divided into two groups. One group contains general parameters which are also used for mineral-oil-based

Table 11
Possible economic activities of *Jatropha curcas* in Indonesia.

Economic activity	Description
Crude *Jatropha curcas* Oil (CJCO)	(CJCO) has been evaluated by Engineering Department Laboratory, Bandung Institute of Technology. This evaluation shows that transesterified CJCO oil achieves better results than the use of pure CJCO oil, straight or in a blend, in unadjusted diesel engines
Jatropha curcas seed cake	*Jatropha curcas* is rich in protein and contain 9–12% oil by weight, 0.446 m^3 of biogas, containing 70% CH_4, per kg of dry seed press cake using pig manure as inoculums using specific developed microbial consortia as inoculum, achieved 0.5 m^3 biogas kg^{-1} of solvent extracted kernel cake and 0.6 m^3 biogas kg^{-1} of mechanically de-oiled cake biogas could be produced from JCL fruit husks and the cake can serve as feed for biogas production through anaerobic digestion before using it as a soil amendment as well, obtained
Jatropha curcas oil use for lighting	*Jatropha curcas* oil is also widely used as a fluorescent, such as at the light signal and equipment of transportation
Jatropha curcas oil for dye	Generally, the oil used in textile industry that able to coloring clothes, finishing nets and lines. The dye may be extracted from leaves, and tender stems and concentrated to yellowish syrup or dried to blackish brown lumpy mass. The form is sulfated *Jatropha curcas* oil such as red turkey oil, which is reported to be used in Indonesia
Jatropha curcas soap	*Jatropha curcas* oil can provide saponification nature of the soap and widely used in Indonesia and other countries. The sodium ricinoleate and sulfo-ricinoleate in castor oil soap can eliminate bacteria.
Paints and varnishes	The discovery of dehydrated *Jatropha curcas* oil processing has increased by development *Jatropha curcas* oil used for support paint industry. *Jatropha curcas* oil is also much utilized in the printing industry and the resin
Medical plant	*Jatropha curcas* oil is widely used as laxatives, for eye irritation and many used as a remedy for food poisoning and diarrhea. *Jatropha curcas* oil possesses purgative properties (urging does 0.3–0.6 cc or 5–10 mL). It differs from castor oil in that it has a low viscosity. The treatment *Jatropha curcas* is obtained by extraction of specific solvent. Because the smell and taste unpleasant, *Jatropha curcas* oil is usually mixed with soda water and syrup "*sarasaparilla*" in its processing. *Jatropha curcas* oil can also be used as a remedy for skin diseases caused by microbes such as fungus because acid are capable of killing bacteria and fungi.

Source of data: [22,104–106].

fuels such as chemical and physical properties, and the other group especially describes the chemical composition and purity of fatty acid methyl esters [109]. The chemical and physical properties of crude *J. curcas* oil are shown in Table 12. In this review, the chemical and physical properties of *J. curcas* oil in different countries around the world were also collected and presented in Table 13.

The major fatty acids in *J. curcas* seed oil are the oleic, linoleic, palmitic and stearic acids. Oleic acid showed the highest percentage of composition followed by linoleic acid [16,80,82,89,91,102,110,111]. The contents of fatty acid from *J. curcas* are presented in Table 14.

Since the kinematic viscosity of *J. curcas* oil is very high, the viscosity of *J. curcas* oil must be reduced for biodiesel application [75]. High viscosity of *J. curcas* oil often causes operational problems such as carbon deposits, oil ring sticking, and thickening and gelling of lubricating oil as a result of contamination by the vegetable oils. Moreover, higher viscosity of *J. curcas* oil can affect the smooth flow of oil in the engine. Different methods such as preheating, blending, ultrasonically assisted methanol transesterification and supercritical methanol transesterification are being used to reduce the viscosity and make them suitable for engine applications [46,78,105]. The kinematic viscosity of crude *J. curcas* oil can be decreased for about 82% after transesterification and amounts to be 4.8 mm^2/s [61,77].

Table 12
Chemical and physical properties of Crude *Jatropha curcas* oil (CJCO).

Parameter	*Jatropha curcas* oil
Density at 15 °C	0.920 g/cm^3
Viscosity at 30 °C	52 cSt
Flash point	240 °C
Fire point	274 ± 3 °C
Cloud point	9 ± 1 °C
Pour point	4 ± 1 °C
Cetane number	38
Caloric value	38.20 MJ/kg
Conradson carbon residue	0.8 ± 0.1 (% w/w)
Hydrogen	10.52 (% w/w)
Sulfur	0 (% w/w)
Oxygen	11.06 (% w/w)
Nitrogen	0
Carbon	76.11(% w/w)
Ash content	0.03(% w/w)
Neutralization number	0.92 mg $KOHg^{-1}$
Saponification value	198.00
Iodine No	94 ± 0.0
Monoglycerides	Not detected
Diglycerides	2.7% m/m
Tryglycerides	97.3% m/m
Water	0.07% m/m
Phosphorus	290 mg/kg
Calcium	56 mg/kg
Magnesium	103 mg/kg
Iron	2.4 mg/kg

Source of data: [68,103,112].

The flash point of *J. curcas* oil is higher as compared to diesel. Due to higher flash point, Jatropha oil has certain advantages over diesel such as greater safety during storage, handling and transport. However, the higher flash point may create initial starting problem of the engine [105]. Compared with biodiesel from edible oils such as palm oil, the oil from *J. curcas* has a lower pour point. Therefore, it may be used in some four season's countries [121].

The iodine value is a measure of the unsaturation of fats and oils. Higher iodine value indicated higher unsaturation of fats and oils [122]. The iodine value of *Jatropha* oil was determined at 101 $gI_2/100$ g, standard iodine value for biodiesel is <120 for Europe's EN 14214 specification (Table 6). In fact, the limitation of fatty acids is necessary due to the fact that heating higher unsaturated fatty acids results in polymerization of glycerides. This can lead to the formation of deposits, deterioration of the lubricating and producing thick sludge in the sump of the engine [102].

Table 15 gives a comparison of *Jatropha oil* and *Jatropha* methyl esters properties with ASTM D6751 and EN 14214 specifications. Table 16 shows chemical and physical properties of Jatropha oil and its blends relative to diesel fuel. Table 17 shows several physical and chemical properties of mineral diesel, *Jatropha* biodiesel and *Jatropha* oil.

3.5. Performance of diesel engines operated with blends of Jatropha methyl esters and diesel

Researchers have tried testing *Jatropha* in diesel engines in many countries around the world and compared the engine performance results with that using fossil diesel under similar conditions. Because of the unusual properties of *Jatropha*, the characteristics

Table 13
Review of physical and chemical properties of *Jatropha curcas* oil in different selected countries.

No.	Properties Physical	Indonesia	Malaysia	Thailand	Myanmar	China	India	Bangladesh	Nigeria	Nicaragua	Ghana	Cuba
1	Density	0.92 g/cm^3	0.90317 g/mL at 20 °C	918 kg/m^3 at 15 °C	–	0.91–0.92 kg/L	940 kg/m^3 at 15 °C	–	0.917 g/cm^3 at 35 °C	0.92 g/cm^3 at 15 °C	860.8 kg/cm^3 at 15 °C	0.9207 g/cm^3 at 15 °C
2	Flash point	340 °C	–	–	–	110–240 °C	225 °C	–	274 °C	240 °C	–	–
3	Kinematic viscosity	75.7 mm^2/s	42.88 cp at room temperature	38.84 mm^2/s at 40 °C	41.51 mm^2/s	-	24.5 mm^2/s	55 mm^2/sat 30 °C	40.4 cp at 35 °C	52 cSt at 30 °C	–	44.31 cst at 20 °C
4	Cetane number	51	–	–	–	–	–	43	51	–	–	
5	Calorific value	39.6 MJ/kg	–	–	–	–	38.65 MJ/kg	39.5 MJ/kg	39.862 MJ/kg	–	–	39.8 MJ/kg
6	Pour point	–	–	–	–	–	4 °C	–	–	–	–	–
7	Specific gravity	–	–	–	0.878	–	–	–	–	–	–	–
8	Solidifying point	–	–	–	–	–	–	−10 °C	–	–	–	–
9	Boiling point	–	–	–	–	–	–	286 °C	–	–	–	–
10	Energy content	–	–	–	–	34 MJ/L	–	–	–	–	–	–
11	Percentage oil content	–	63.16 ± 0.35	–	–	–	–	–	–	–	–	–
	Chemical											
12	FAME content	–	–	–	–	–	–	–	–	–	–	–
13	Free fatty acid (FFA)	–	2.23 ± 0.02%	0.52%w	22.6%	–	–	–	–	–	–	–
14	Saponification value	–	193.55 ± 0.61	–	208.27% mg KOH/g-oil	–	–	–	198	–	–	–
15	Iodine value	–	103.62 ± 0.07	-	100.1	–	-	–	112.5	–	–	–
16	Carbon residue	–	–	–	–	–	1.0%	–	0.64%	–	–	–
17	Ash content/sulfuric acid	–	–	–	–	–	0.8%	–	38.2%	–	–	–
18	Acid number	–	–	–	–	–	28.0 mg KOH/g	–	-	–	–	–
19	Water content	–	–	0.125%w	–	–	1.4%	–	-	0.07	–	0.21%wt
20	Sulfur content	–	–	–	–	0.13%	-	–	0.13%	-	–	0.04%wt
21	Phosphorus content	–	–	–	–	–	–	–	-	290	–	–
22	Peroxide value	–	1.93 ± 0.012	–	–	–	–	–	-	–	–	–
23	Calcium	–	–	–	–	–	–	–	56 ppm	–	–	–
24	Magnesium	–	–	–	–	–	–	–	103 ppm	–	–	–
25	Iron	–	–	–	–	–	–	–	2.4 ppm	–	–	–
26	Moisture content	–	–	–	0.2%	–	–	–	–	–	–	–
27	Total glycerol	–	–	–	8.27%	–	–	–	–	–	–	–
28	Free glycerin	–	–	–	0.58%	–	–	–	–	–	–	–
29	Combine glycerin	–	–	–	7.60%	–	–	–	–	–	–	–
30	Diglycerides	–	–	–	–	–	–	–	–	2.7	–	–
31	Triglycerides	–	–	–	–	–	–	–	–	97.3	–	–

Source of data: [60,68,69,102,113–120].

Table 14
Fatty acid composition of *Jatropha curcas* oil.

No.	Fatty acid	Structure[a]	Formula	Composition (wt%)
1	Myristic	(14:0)	$C_{14}H_{28}O_2$	0–0.1
2	Palmitic	(16:0)	$C_{16}H_{32}O_2$	14.1–15.3
3	Palmitoleic	(16:1)	$C_{16}H_{16}O_2$	0–1.3
4	Stearic	(18:0)	$C_{18}H_{36}O_2$	3.7–9.8
5	Oleic	(18:1)	$C_{18}H_{34}O_2$	34.3–45.8
6	Linoelic	(18:2)	$C_{18}H_{32}O_2$	29.0–44.2
7	Linolenic	(18:3)	$C_{18}H_{32}O_2$	0–0.3
8	Arachidic	(20:0)	$C_{20}H_{40}O_2$	0–0.3
9	Behenatic	(22:0)	$C_{22}H_{44}O_2$	0–0.2

Source of data: [6,103,104,111].
[a] Carbon in the chain: double bonds.

of injection, atomization and combustion tend to differ. All these variations can lead to many difficulties when using *Jatropha* methyl esters in diesel engines. The literature shows a significant performance variations obtained from selected countries. In this review, many engine performance parameters were collected such as brake specific, specific fuel consumption, brake power, torque, brake thermal efficiency, emission etc. Detailed engine performance results have been collected from many countries around the world and depicted in Table 18.

3.6. *Jatropha curcas as a feedstock for biodiesel in Indonesia*

The area of agriculture in Indonesia represents 60% of total land. This area is huge enough to generate the *J. curcas* plantation that can be used for large-scale production of biodiesel. Recently, *J. curcas* has been promoted as a feedstock for biodiesel in Indonesia. Since it is not edible, therefore, it will reduce the potential conflict of food versus energy issue. *J. curcas* is also growing well at a wide range of soil textures such as soil with high mineral content, sandy soil or clay soil with good drainage. This plant has also been found to be appropriate for land conservation.

Substantial interest has been generated in *Jathropa Curcas* and it is explicitly targeted within the domestic biofuel policy documentation despite the lack of commercial projects. According to local developers in Indonesia, a business model for *Jatropha* based on biofuel production alone is not feasible. The oil is only a minor part of the revenue and therefore carbon financing and biogas produced from residues are required. Employment statistics vary depend-

Table 15
Comparison of properties *Jatropha oil*, *Jatropha* methyl esters, ASTM D 6751/EN 14214 specifications and diesel fuel.

Properties	Jatropha oil	JME	EN 14214	ASTM D 6751	Diesel
Density at 15 °C (kg/m^3)	918	879	860–900	875–900	850
Kinematic viscosity at 40 °C	35.4 mm^2/s	4.84 cSt	3.5–5.0 mm^2/s	1.9–6.0 mm^2/s	2.6
Acid value (mg KOH/g)	11	0.24	0.5 (Maximum)	0.5 (Maximum)	0.35
Flash point °C	186	191	>101 (Minimum)	130 (Maximum)	70
Cetane number	23	51	51 (Maximum)	47 (Minimum)	46
Sulfated ash	–	0.014 wt%	0.02 wt%	0.02 wt%	–
Water	5%	0.16 mg/kg	0.05 mg/kg	0.05 mg/kg	0.02
Conradson Carbon residue	0.3	0.025	<0.30% m/m	<0.050 wt%	0.17
Iodine number (g/100 g)	101	86.5	<120	–	–
Free glycerol	–	0.015 wt%	0.02 wt%	0.02 wt%	–
Total glycerol	–	0.088 wt%	0.24 wt%	0.25 wt%	–
Calcium	–	6.1	5 ppm (Maximum)	5 ppm (Maximum)	–
Magnesium	–	1.4	5 ppm (Maximum)	5 ppm (Maximum)	–

Source of data: [7,21,103].

Table 16
Chemical and physical properties of *Jatropha* oil and its blends relative to diesel fuel.

Property	Units	Fuel blend				
		0/100	50/50	80/20	97.4/2.6	100/0
Density at 15 °C	kg/m^3	917.7	891.7	876.9	868.4	866.9
Kinematic viscosity at 37.8 °C	cSt	36.9	14.6	8.2	5.9	5.7
Flash point	°C	99	94	90	88	86
Pour point	°C	−3	6	12	15	15
Caloric value	Mj/kg	42.048	43.099	44.15	45.202	45.90

Source of data: [123].

Table 17
Fuel properties of mineral diesel, *Jatropha* methyl esters and *Jatropha* oil.

No.	Property	Mineral diesel	*Jatropha* methyl esters	*Jatropha* oil
1	Density (kg/m^3)	840 ± 1.732	879	917 ± 1
2	Kinematic viscosity at 40 °C (cSt)	2.44 ± 0.27	4.84	35.98 ± 1.3
3	Pour point (°C)	6 ± 1	3 ± 1	4 ± 1
4	Flash point (°C)	71 ± 3	191	229 ± 4
5	Conradson carbon residue (%, w/w)	0.0	0.01	0.8 ± 0.1
6	Ash content (%, w/w)	0.01 ± 0.0	0.013	0.03 ± 0.0
7	Calorific value (MJ/kg)	45.343	38.5	39.071
8	Sulfur (%, w/w)	0.25	<0.001	0
9	Cetane No.	48–56	51–52	23–41
10	Carbon (%, w/w)	86.83	77.1	76.11
11	Hydrogen (%, w/w)	12.72	11.81	10.52
12	Oxygen (%, w/w)	1.19	10.97	11.06

Source of data: [124].

Table 18
Review of comparative engine performance with blend of *Jatropha* biodiesel and diesel in different selected countries.

Countries	Engine model	% of Blends	Engine power rpm	Engine performance test									Exhaust gas						
				Brake power kW	Torque Nm	Brake mean effective pressure kN/m^2	Brake specific fuel consumption g/kW-h	Mass of fuel kg/h	Brake thermal effi-ciency %	Mass of air kg/h	Air fuel ratio	Temp. exhaust °C	CO_2%	O_2%	CO	SO_2 (ppm)	NOx (ppm)	HC (ppm)	Black smoke (%)
Bangladesh	06-TCVenaria, Vertical, 4 cylinder, in line, air-cooled, diesel cycle	B50	–	0.399	–	–	1298	0.44	10.8	8.49	19.3	–	5	8	1%	–	–	–	–
Indonesia	Motor Diesel Chang Chai SX 175	B40	1600	1.47	9000	–	–	–	43	–	–	–	1.367	–	706.556 ppm	32.556	137.111	171	–
Thailand	ISUZU EFL 250 Truck, 2,369 cc 4 cylinder, water cooled diesel	B30	2000	22.49	107.33	-	300	–	–	–	–	–	10		500 ppm	–	–	–	9.2
India	Single cylinder open combustion chamber C.I. by Kirloskar Oil Engines Ltd	B50	–	–	–	–	693	–	22.44	–	–	535				–	–	–	–
China	ZS 195 Diesel by Nanji Machinery Ltd	–	1500	–	–	–	290-510	–	0.2-3.5	–	–	–	–	–	20–25 ppm	–	250–1480 ppm	17–23 ppm	
Ghana	Lister Single-cylinder engine, air cooled, direct injection, 4 stroke	B50 preheated	B50 preheated	0.36-1.35	–	–	480-1300	–	6.6-9.3	–	–	245	0.2-2.4	14.6-16.2	100–262%	–	–	–	–
Nigeria	3.26 Hp Single cylinder four stroke 165 F compression ignition in corporated with 1.25 kVA Honda E 1500	B20	2600	2	–	37.62	812.2	–	32.39	–	–	150	–	–	–	–	–	–	–

Source of data: [68,69,113,123,125–127].

Table 19
Potential of *Jatropha curcas* L. cultivation area distribution in Indonesia.

Province	S_1 (Most appropriate)	S_2 (appropriate)	S_3 (Less/marginal appropriate)	Total
Nanggroe Aceh Darussalam	180,139	160,764	836,001	1,176,904
North Sumatera	215,393	–	1,390,475	1,605,868
West Sumatera	4,269	–	781,189	785,458
Riau	80,718	–	1,600,844	1,681,562
Jambi	218,284	–	993,134	1,211,418
South Sumatera	530,207	–	3,229,784	3,759,991
Bengkulu	–	–	602,022	602,022
Lampung	718,823	66,023	706,931	1,491,777
Kepulauan Bangka Belitung	156,319	–	947,881	1,104,200
West Java	231,011	445,022	306,989	983,022
Middle of Java	494,630	74,416	338,824	907,870
Daerah Istimewa Yogyakarta	35,227	33,999	8,454	77,680
West-East Nusa	37,877	428,539	124,466	590,882
East-SoutheastNusa	595,421	833,293	322,174	1,750,888
West Kalimantan	67,463	984,340	3,897,005	4,948,808
Middle of Kalimantan	171,063	–	3,632,324	3,803,387
South Kalimantan	833,745	48,559	623,326	1,505,630
East Kalimantan	3,643,059	680,468	2,878,161	7,201,688
North Sulawesi	143,760	–	538,555	682,315
Middle of Sulawesi	506,887	–	373,638	880,525
South Sulawesi	435,483	122,407	613,780	1,171,670
Southeast Sulawesi	1,015,825	27,248	177,833	1,220,906
Gorontalo	290,146	13,701	–	303,847
Maluku	766,888	162,982	316,223	1,246,093

Source of data: [86].

ing on the business model from one farmer for every 3 ha to four farmers per hectare [57].

Jatropha is a drought resistant crop and can be produced in most part of Indonesia, especially in the dry south eastern part of South Nusa Islands. It is a strong and highly productive plant, easily maintained and it is not a food producing plant. Many analysts believe that diversifying biodiesel feedstock to *Jatropha* can stimulate the economy of a less fertile and dry area of Indonesia, can ease the burden of competition between food supply and energy supply in palm oil and along with it, ease the pressure on protected rain forests around the country.

According to the Indonesian government, an area of 94,000 ha had already been planted with *J. curcas* nationwide by the end of December 2007. Fig. 19 shows possible locations of *J. curcas* plantations in Indonesia. Table 19 shows the potential of *J. curcas* L. cultivation in Indonesia. Table 20 shows development of industry of biodiesel in 2009 in selected provinces.

Table 20
Development plan of biodiesel industry in 2009.

Province	Palm oil (ha)	*Jatropha curcas* (ha)	Production biodiesel (ton/year)
Nanggroe Aceh Darussalam		10,000	16,000
North Sumatera	40,000	–	141,500
Riau	93,000	–	325,500
South Sumatera	6,000	–	35,000
Bengkulu	6,000	–	35,000
West Java	–	6,000	9,500
Middle of Java	–	20,000	32,500
West Kalimantan	12,000	–	42,000
Middle of Kalimantan	12,000	–	43,000
East Kalimantan	10,000	–	35,000
South Sulawesi	10,000	20,000	69,000
Southeast Nusa	–	120,000	203,000
Total	189,000	176,000	987,000

Source of data: [130].

In November 2007, *J. curcas* cultivation on Sumba, East Nusa Tenggara, was established and demonstration plots to East Sumba's capital Waingapu has found out that this area is full of "marginal lands", but they are not "empty". They are sparsely populated; however, the local population considers them part of their ancestral lands, held either communally under *adat* law (Heritage law) or in some cases even state-registered as cultivation land. The Agricultural activities of *J. curcas* cultivation in Central Sumba has been promoted since 2005. In Tana Modu, Central Sumba, farmers were urged to plant *J. curcas*. This plant has been known here since the Second World War, when Japanese soldiers introduced it to make oil for lamps and also the leaves were used as medicine. With relatively simple equipment, a neighborhood community could produce their own biodiesel for certain kinds of engines and thus save expensive fossil fuel [128].

3.6.1. Development of Jatropha curcas in Indonesia

In Indonesia, there are many development plans for *J. curcas* plantation. Some of recent known development plans are shown in Table 21.

3.7. Impact of Jatropha curcas oil as a biodiesel

Utilization of biodiesel in the agricultural sector is faced with many challenges and opportunities. Various researches state that biodiesel industry will have an impact on food production. Therefore, *Jatropha* is one of good choices of biodiesel industry in Indonesia. In the following section, we will present the emissions, environmental, economic and social impacts of *J. curcas*.

3.7.1. Emissions impact

Biodiesel emits fewer emissions such as CO, PM and HC compared to diesel. However, it emits Higher NO_x emission than diesel [28,52,71,131–134]. Table 22 summarizes the average emission changes found by EPA for B_{20} and B_{100}. Summary of United States EPA evaluation of biodiesel impacts on pollutant emissions

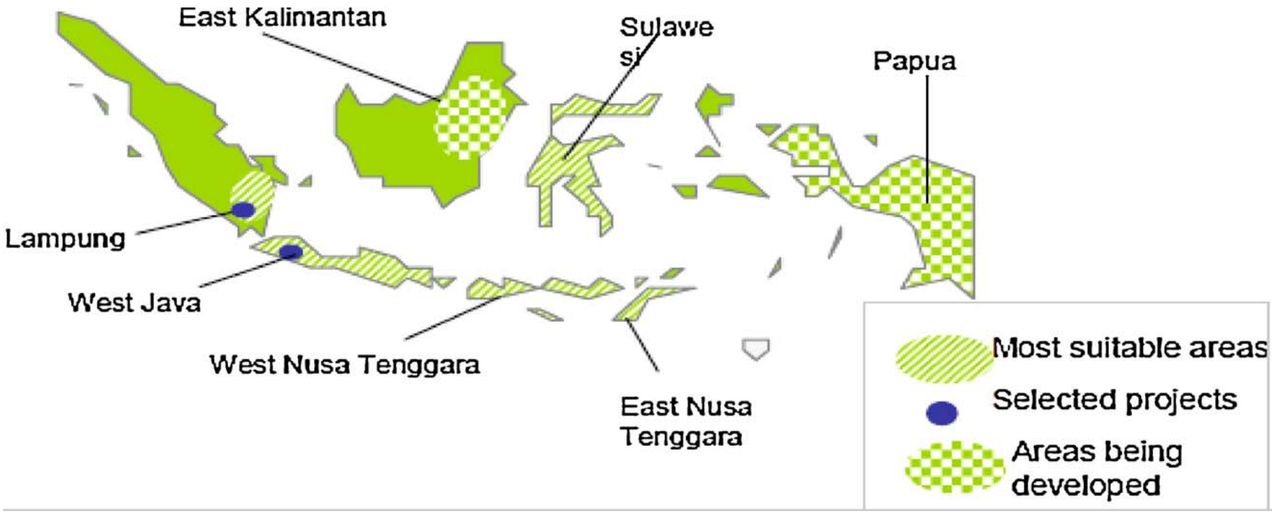

Fig. 19. *Jatropha curcas* plantations in Indonesia.

Source: [129].

Table 21
Key development plans of *Jatropha curcas* in Indonesia [87].

Organization	Category	Plan
Rajawali Nusantara Indonesia (RNI)	Company	Developing some 2000–2500 ha of *Jatropha curcas* in Purwakarta, West Java
Institut Technologi Bandung (ITB)	Education	Plantation of 12 ha (30,000 trees) in Southwest Nusa (NTB)
PT. Energi Alternatif Indonesia	Company	Planning to plant 48,000 trees in Southwest Nusa (NTB)
Departemen Pertanian (Department of Agriculture)	Government	Has planted 3000 trees in Southeast Nusa
ITB, IPB, & Department of Social Affairs)	Education + Government	Plantation of 400 ha in critical soils, Bireun, Nanggroe Aceh Darusasalam.
Pertamina, ITB, PT. Rekayasa Industri	Company + Education	Signed an MoU on 18th August 2005 to develop a biofuel project (location unspecified) to work on three levels 1—A small scale Biofuel Factory - with a capacity of 1000 l per day from 200 to 250 ha 2—A medium scale Biofuel Factory - with a capacity of 15,000 l per day from 4,250 ha. A large-scale Biofuel Factory—to produce 100,000,000 l per annum from 98,000 ha
Badan Pengkajian Penerapan Teknologi (BPPT), the Department of Technology	Government	Developing of a *Jatropha curcas* estate. This estate is reported to be located on the island of Sumba (Southeast Nusa) and to cover some 20,000 ha of land.
Mitsui, Japan	Company	Plantation of 5000 ha *Jatropha curcas* estate in East Kalimantan to produce and export biodiesel to Japan
PT. Bara Indah	Company	Plantation of 3000 ha *Jatropha curcas* estate in South Kalimantan

Source of data: [87].

for heavy-duty engines are summarized in Fig. 20. Studies also show significantly lower levels of emissions of specific toxic compounds for biodiesel and biodiesel blends, including aldehydes, PAH, and nitro-polyaromatic hydrocarbons [16,135,136]. Table 23 shows CO_2 emission factors of diesel and biodiesel, respectively. Moreover, the potential mitigation of CO_2 emission produced from substitution of biodiesel in the middle term and long term is shown in Table 24.

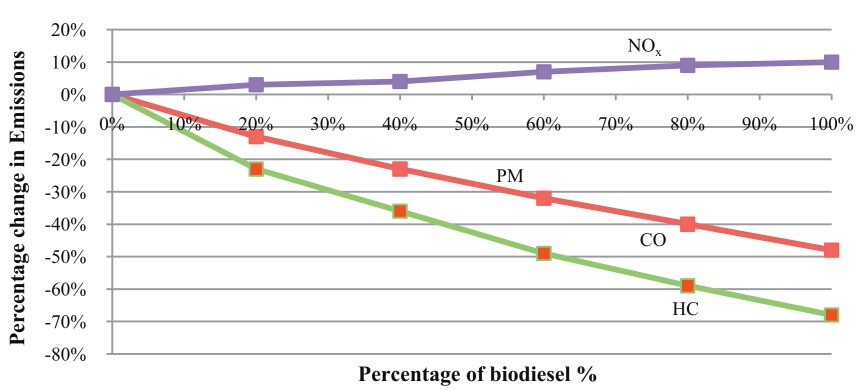

Fig. 20. Summary of United States EPA evaluation of biodiesel impacts on pollutant emissions for heavy-duty engines.

Source: [135,136].

Table 22
Average heavy-duty emission impact of 20% and 100% biodiesel relative to average conventional diesel fuel.

Air pollutant	Change for B_{20} (%)	Change for B_{100} (%)
NO_x	+2.0 to −2	+10
PM	−10.1	−47
CO	−11.0	−48
Hydrocarbon	−21.1	−67
Sulfates	−20	−100
PAH (polycyclic aromatic hydrocarbons)	−13	−80
nPAH (nitrated PAH's)	−50	−90

Source of data: [16,135,136].

Table 23
CO_2 emission factors of diesel and biodiesel.

Type of fuel	Emissions CO_2 (kg/TJ)
Diesel	74,100
Biodiesel	70,800

Source of data: [130].

3.7.2. Environmental impact

Assessing the long-term environmental consequences of biodiesel feedstock production is a complex task. Life-cycle reductions in carbon-dioxide emissions depend on the source of the feedstock, production pathways, and the assumptions made regarding alternative uses of the land from which the feedstock was produced, especially if the land had previously been forested [137].

One of *Jatropha's* most attractive characteristics is its ability to withstand drought and grow in arid and semi-arid areas with low rainfall and poor soil fertility [81,89]. *Jatropha* may be used to control soil erosion [90,100], especially in semi-arid areas, and its seedcake can be used to improve soils. Moreover, *J. curcas* tree is a nitrogen-fixing plant and established as one of the best instruments that generate more oxygen back to ozone. As a natural fence, *Jatropha* can assist farmers in preventing conflicts with endangered wildlife. The *Jatropha* biofuels value-chain may lead to significant reductions in greenhouse gas emissions, although more research is necessary to ascertain these impacts over the entire life cycle of growing, energy production, and use. Existing research indicates that biodiesel production from *Jatropha* is predicted to be generally positive in comparison to the use of fossil diesel, although the significance of this positive energy balance depends on the specific methods for growing, transporting, and processing, which tend to be project specific. However, land-use changes associated with new plantations, especially on land not previously used for agriculture, can require years of new plant growth to re-sequester the carbon that is lost during land clearing. *Jatropha's* toxicity may present potential environmental and public health problems. One researcher has warned that the curcanoleic acid contained in the oil may promote skin cancer and that the oil can cause skin irritation to farm workers. *Jatropha* is also considered invasive in many parts of the world, including South Africa, Hawaii, and Australia [138].

Table 24
The potential mitigation of CO_2 emission produced from biodiesel.

Parameter	Unit/year	Middle term (2010–2015)	Long term (2015–2025)
Subtitution	Ton oil	6,000,000	16,000,000
Mitigation emission CO_2	Million ton	19 .12	50 .98

Source of data: [130].

In Indonesia some estimates claim that more than 2 mha are deforested and degraded each year. About 50% of the country's forests are degraded and 54% of that remaining is threatened. Serious environmental impacts of forest clearance include land degradation and desertification, loss of biodiversity (especially in protected areas), soil and water loss, changes in nutrient cycling, flooding and siltation, air pollution (smoke hazes from set fires) and net CO_2 emissions in quantities that significantly contribute to global warming and climate change [139]. Therefore, plantations projects of *J. curcas* in Indonesia will work hand in hand with the people to cover back the green to all the deforested areas by *J. curcas* which have more economic value to people and environmental friendly to the mother nature and the solution for cutting down the emission of CO_2 and help give enough time for mankind to save our earth for our next generation.

Indonesia possesses a remarkable and valuable natural environment that represents an ideal option for biofuel farming. Moreover, Indonesia's huge land forest areas function as *Jatropha* plantation such as Java, Papua, West Kalimantan, West and East South Nusa represent an important aspect of mitigating emission and avoiding climate change. This offers a stable, low-cost environment, coupled with supportive government policies for the sustainable and profitable cultivation of *Jatropha* for abundance of landless farmers and favourable rainfall pattern.

3.7.3. Economic and social impact

Jatropha oil offers greater returns to labor and agricultural land as well as additional benefit including a shorter fallow period. Kumar and Sharma [80] highlighted some of the economic significances of *Jatropha*. The set up of JTC oil converting industries would create employment opportunities, provide a source of income for farmers and suppliers of feedstock and would, eventually, be a great source of revenue for governments. Also, it will reduce the dependency on fossil fuels and minimize crude petroleum import costs [140]. With the demand for *J. curcas* biodiesel, there will be increasingly widespread commercial cultivation of *J. curcas* in Indonesia. Therefore, *J. curcas's* potential to alleviate poverty in this country is very high. The current knowledge gaps and uncertain economic perspectives, together with competition on the global biofuel market, might drive *J. curcas* investor away from marginal or degrade lands towards agricultural or lands that are valuable for biodiversity. In order to reduce financial risk, *Jatropha* needs resources like any crop to achieve high productivity [141]. However, it seems that yields will not be very attractive, as the local market price of CJCO for biodiesel is not competitive with the prices of diesel due to the following reasons [142]:

- The price of *J. curcas* seed is about 750 IDR/kg (farmers income).
- The feedstock cost of *J. curcas* oil is 3000–3500 IDR/kg.
- The oil mill cost (including de-gumming) is 500 IDR/liter-oil.
- The production cost of biodiesel is 1000 IDR/L.
- The total cost of biodiesel is 4500–5000 IDR/L.
- The international price of kerosene is 5000 IDR/L but Indonesian Government subsidy 60% (3000 IDR/L) of the price.

CJCO has been engaged in promoting sustainable farming for biodiesel production since the last decade. Indonesia has focused on the development of *J. curcas* and other non-food biodiesel crops. Their primary goal is to discover and develop high-yielding crops that try to change the traditional farming system to be familiar with bioenergy per hectare of land. In different parts of the world, many farmers have been encouraged to use biodiesel for irrigation purposes through *J. curcas* cultivation. This policy stimulates economic empowerment of *jatropha* biodiesel. The contribution of *J. curcas* to rural livelihoods is huge. Fig. 21 shows some of the ways that households may benefit from *J. curcas* in theory and some of the social

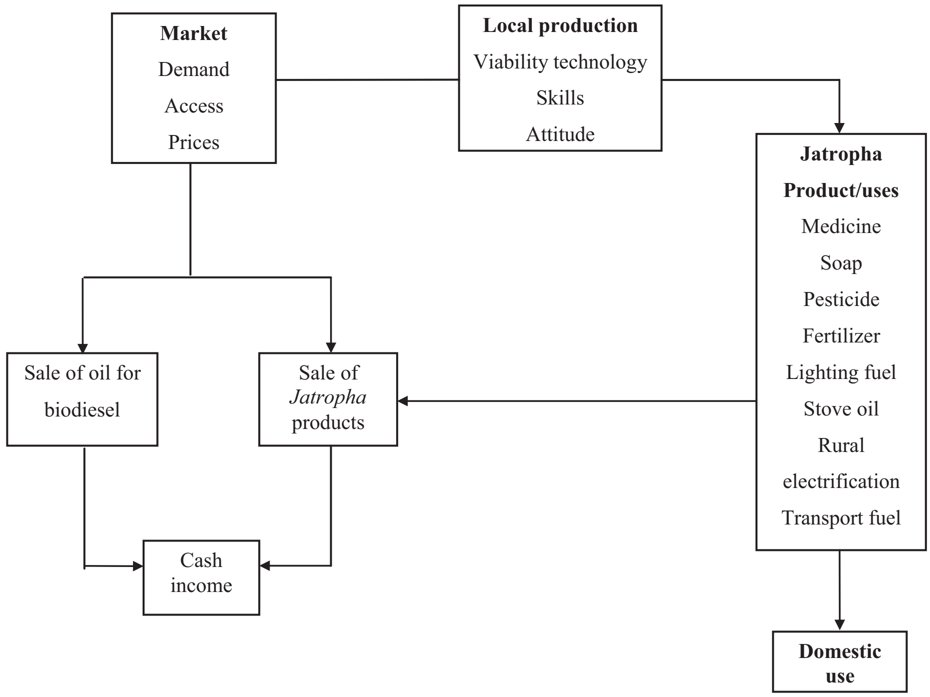

Fig. 21. Possible benefits from *Jatropha curcas* for households.

Source: [143].

and economic determinants are discussed in the following section. [143].

From the above figure, it appears that the opportunity for local populations to maximize benefits from *Jatropha* is to engage not only *Jatropha* production but also in oil extraction. The raw oil extraction can be improved using better extraction techniques, which can enhance the economics of biodiesel production process.

4. Development of biodiesel markets in Indonesia

A feasibility study to determine the communities' willingness to participate in the production and marketing of biodiesel, increase income generation and alleviate poverty found out that there is a growing interest in biodiesel, fueled by the demand from developed and developing countries for a number of reasons, mainly the increasing fossil fuels prices and the demand for reducing Greenhouse Gases (GHG) emissions.

A few years back, biodiesel market had very limited recognition in Indonesia as an alternative source of energy. However, conditions are different now. Indonesia started to develop the biodiesel industry in 2006 as a response to a progressive price increase of fossil-based oil in the world, declining domestic crude oil production and considerable progressive increase in domestic oil consumption. In June 2006, Indonesia started to sell biofuel in the form of bio-solar, bio-pertamax and bio-premium through PT Pertamina, the state-owned Oil and Gas Company. Since then, the use of biofuel has been increasing as can be seen in Table 25 [144].

Table 25
Biofuel sale in Indonesia.

Type of biofuel	2006 (kL)	2007 (kL)	January–June 2008 (kL)
Bio-solar	217,048	555,141	285,240
Bi premium	1,408	3,776	2,000
Bio-pertamax	16	9,958	7,456

Source of data: [59].

Indonesia has the potential to become one of the major producers of biodiesel in the world. The government encourages private companies to build more processing plants and promoted biodiesel for vehicles and power (electricity) generation. To increase marketing of biodiesel, the government has made the development of the biodiesel industry into a high priority venture, through the creation of subsidy and farmer support programs such as *jatropha* Indonesia. Currently, Indonesia has started the green energy program to produce CJCO, the expansion of *jatropha* oil based biodiesel production potential was being constructed across many local industry biodiesel [145].

5. Conclusion

In conclusion, this paper found out that production of biodiesel from *J. curcas* offers many social, economical and environmental benefits for Indonesia and can play a great role to solve the problem of energy crisis in Indonesia.

J. curcas is a small tree or large shrub belonging to the Euphorbiaceae family. The plant has its native distributional range in Mexico, Central America, Brazil, Bolivia, Peru, Argentina and Paraguay and different other parts of the world. *J. curcas* offers many benefits, some of these benefits are: it costs nothing to grow, it creates jobs opportunities, it recycles 100% of the CO_2 emissions produced by burning the biodiesel, it makes soap and glycerin, its waste plant mass after oil extraction can be used as a fertilizer etc.. . .. *Jatropha* is one of the biodiesel resources that offer immediate and sustained greenhouse gas advantages over other biodiesel fuels. Globally, *Jatropha* has created an interest for researchers because it is non-edible oil and can be used to produce biodiesel with same or better performance results when testing in diesel engines. The main problem of *Jatropha* as a biodiesel is its high fatty acid. Moreover, it still needs filtration and transesterification process required to upgrade oil characteristics before admix to biodiesel.

Energy is fundamental to the quality of life on the earth. Meeting the growing demand for energy sustainably is one of the major

challenges of the 21st century. Indonesia is a developing country and the world's fourth most populous nation. Total annual energy consumption increased from 300,147 GWh in 1980, 625,500 GWh in 1990, 1,123,928 in 2000 and to 1,490,892 in 2009 at an annual increase of 2.9%.

Presently, fossil-fuel-based energy such as oil, coal, and natural gas are the major sources of energy in Indonesia. In 2009, oil was the largest single source of energy (48%) followed by natural gas (26%), coal (24%) and renewables (2%). In 2007, the transportation sector was the second largest consumer of fossil fuel from the total national energy consumption (33%) following the industrial sector (48%). Although the entire Asia-Pacific region has recorded some declines in oil supplies Indonesia has reported more severe reduction in fossil fuel supplies during the last 12 years. This reduction in oil supply has stimulated promoting the usage of renewable energy resources capable of simultaneously balancing economic and social development with environmental protection. Biodiesel is one of these resources and has immense potentiality to be a part of a sustainable energy mix in the future. Globally, annual biodiesel production increased from 15,000 barrel per day in 2000 to 289,000 barrel per day in 2008. In Indonesia, annual biodiesel production increased from 14.5 thousand barrel per day in 2008 to 16.2 thousand barrel per day in 2009 at average increase of 11.7%. It is expected that biodiesel production will increase substantially in Indonesia in the near future due to the availability of bulk biodiesel feedstock such as palm oil and *J. curcas*.

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